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SORGHUM NUTRITIONAL QUALITY IMPROVEMENT[1]

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I. INTRODUCTION

Sorghum has had very extensive use as a food crop in Africa and Asia and as a major feed grain in North America and more recently in South America. In spite of this extensive use, improving the nutritional quality of the sorghum grain has received little interest in experimental work until recently. Sorghum varieties have been selected primarily for their yield and resistance to drouth, diseases and insects, and acceptability preferences. Sorghum has been grown primarily in drier areas of each continent during the season of summer rainfall.

A. Natural Variability

In recent years extensive variability in sorghum grain quality has been noted. These quality factors include protein amount, amino acid composition and digestibility in addition to the ever present yield, resistance and adaptation factors incorporated into varieties. The availability of hybrids in 1956 brought about extensive increases in yield, resistance and adaptation factors incorporated into varieties. The availability of hybrids in 1956 brought about extensive increases in yield, resistance and adaptation factors incorporated into varieties. The availability of hybrids in 1956 brought about extensive increases

increases in yield, where they were used, and simultaneously a decline in protein percentage. In general this negative relationship holds there with all of the major grassy cereals, including rice, wheat and maize. That is, when yield goes up protein declines unless management and selection pressures are applied to remove this reaction. Simultaneously or just immediately following the development of hybrids, a world collection was brought together (in the years 1958-63 by The Rockefeller Foundation). This collection revealed a tremendous variation of phenotypes and nutritional factors of interest.

B. Sorghum Production

As improved varieties and hybrids became available, management problems were improved along with them and new yield horizons opened up to the point that yields were vastly increased. The traditional grain sorghum production methods gave yields of sorghum grain from 500 to 700 kg/ha. Improved fertility and management practices under the most favorable conditions have brought about commercial hybrid yields of over 13,000 kg/ha in the United States. In exceptional circumstances experimental yields of over 10,000 kg/ha have been relatively frequent and average good farm yields have reached 8500 kg/ha. In Africa, variety yields above 4500 kg/ha are quite rare, being found only in relatively small improved fields. Some of these low yields are associated with the season of growth such as when the grain is matured in the dry season, poor soil fertility. and lack of disease, insect, bird and rodent control. Also important in yields are effective management factors including, growing sorghum in a rotation with other crops—especially legumes, good seed availability, seedbed preparation, proper seeding rate, early thinning, water and drainage management, weed control, proper harvest and storage. As land pressures increase there will be a real pressure for increased yields and nutritional value to be obtained from each hectare. A major factor in higher production for many areas is to get varieties with more weathering and pest resistance so that grain may be produced when moisture is more available.

C. Food and Feed Uses

In areas where sorghum is a food crop the food preferences of each particular area have imposed a severe restriction on the types of grain that may be used in variety development. In India the selection is primarily for the white, creamy white to yellow and pearly types. In Africa the variability of preference is tremendous with isolation being a primary factor in such food preferences.

Almost all sorghum consumption the world over has been of the whole grain. In India it is used in unleavened bread and in much of Africa it is a primary ingredient for porridge or much with many types being used in preparation of beer. As a feed grain in the United States it has been utilized as a whole grain, but more extensive methods of preparation have been used such as grinding, steam rolling and other treatments in a deliberate attempt to improve the intake and nutritional value.

Grain sorghum studies have shown a great variation in digestibility and feeding response for all classes of animals tested, as well as for human nutrition. Studies concerning the improvement of amino acid composition and digestibility have been limited and slowed due to the complicated factors of ease of assessment of these values and interaction of environment and management factors. Environmental and management factors interact with variety responses to produce grain which differs greatly in nutritional value as well as yields. Studies on nutritional improvement of cereals were held back until the advent of opaque-2 maize by the belief that as yield went up protein had to go down and as protein went up the limiting amino acids had to decrease.

II. ENVIRONMENT AND MANAGEMENT EFFECT ON NUTRITIONAL QUALITY AND YIELD

A. Soil Fertility Effects

Nitrogen fertilization increased the level of protein (Waggle, et al., 1967) in several U.S. commercial hybrids from 9.1 to 12.6% protein. While this happened the amino acid, lysine, was increased also, but at a slower rate from 0.22 to 0.25% of the grain. Another limiting amino acid, threonine, was also increased at a much slower rate similarly to lysine, while several less essential amino acids such as glutanic acid, proline, alanine, isoleucine and leucine were increased to a greater degree with higher nitrogen fertilization. Tests at three sites showed a significant location effect on yield and protein level.

Studies (Campbell and Pickett, 1968) reported a significant effect of four nitrogen levels on 18 lines selected from the world collection. The relatively large genotypic differences for protein and lysine noted in this experiment, persisted under all four fertility levels tested and were much more important than the differences due to the specific fertility treatments. The negative correlation of protein and lysine was significant ($r = -.1214^{**}$), but much lower than previous data on many crops would suggest. Some of the higher protein and lysine genotypes had relatively high yield potential as indicated by data on panicle size under comparable populations.

The adjustment of pH on some soils may be critical to the minimal production of sorghum and also the protein quantity and quality. In many tropical soils that are highly acid, the availability of phosphorus can be a problem and Al and Mn toxicity can be critical. Zinc, copper, molybdenum and sulfur deficiencies are the result of other limiting trace elements that have been found in some places. All of these factors are important for consideration in order to consistently expect higher yields and improved quality.

B. Plant Population and Planting Pattern

The number of plants per acre should be adjusted to the amount and pattern of moisture available. In extreme dry zones the population may be down to 40,000 plants per hectare. With more adequate moisture the population should be increased to 120,000 or 150,000 plants per hectare. Under the most favorable conditions it will be up to 300,000 plants per hectare or more. Sorghum has a great ability to compensate for low populations through basal and nodal tiller production. Basal tillers are a primary contributor to yield and are of particular value when they have a similar height and maturity as the main stems. Thus tillering and total plant survival influence yield and composition. Head number and weight of grain per head are drastically effected by population but seed size may also be adversely affected later in the growing season by adverse conditions. Anything that drastically reduces yield may result in shriveled seed. This shriveled seed will be significantly higher and more variable in protein percentage and the energy availability of immature sorghum grain is lower (Deyoe et al., 1970).

Under the drier condition and lower population situations, wide rows are necessary (100 cm or more), but under more favorable moisture conditions row widths to the maximum of 75 cm or less should be used. Under the most favorable conditions it is advisable to go down to 15 to 35 cm. When closer rows and higher population can be used they offer advantages of weed control and moisture retention under dense leaf canopies. This in turn can result in higher yields from a given moisture level.

C. Weed and Pest Control

Weed control in subsistence agriculture is often quite ineffective but may be assisted by adequate population and timely weeding. In improved agriculture weed control by Atrazine-Ramrod mixed at a ratio of 2.5 kg/ha and 5 kg/ha or Propazine at the ratio of 2.5 kg/ha can be used. If weed control is inadequate, drastic reduction in yield may occur. Similarly, thinning, if it is part of the cultural practice, must be done early to avoid a drastic reduction in yield.

Resistances are necessary to the major diseases and insects in the area concerned in order to get economical yields. The insects and diseases that attach sorghum are summarized by Wall and Ross (1970). If economical yields are not possible due to lack of resistances or other factors there is no interest in types with improved nutritional value. In some areas this fact has retarded the investigations for improved nutritional values. Thus diseases and insects plus birds and rodents are not only critical to production, but their control is necessary followed by effective grain storage of any nutritional grain that may be produced. Storage in order to maintain food and feed supplies is influenced by low humidity with low temperatures being secondary and pest control. The study of sorghum storage procedures with the development of adequate and economically acceptable control will continue to improve the sorghum production.

D. Water Management

Sorghum is usually produced during the intense rainy season, on river flood plains in many parts of Africa and under irrigation in Asia where both surface and internal soil drainage are absolutely necessary for optimum production. Soil alkalinity and salt accumulations in some areas are primary limiting factors. If irrigation is used it should be adequate and dependable for as much of the growing season as possible. The influence of water management on sorghum grain quality merits further investigation (Miller, et al., 1964).

III. GENETIC IMPROVEMENT

A. Variability in the Sorghum Collection and Breeding Materials

The Rockefeller Foundation sorghum collection gathered by cooperators all over the world in 1958-63 numbered over 5,000 viable lines. Since that time several thousand additional lines have been added and now the collection numbers over 15,000. Utilization of this collection has allowed plant breeders to be aware of nutritional improvement and has broadened the base for variety development and hybrid production. This tremendous reservoir of natural variability will be supplemented for several years by additional lines collected in Africa and Asia. Several lines from the collection have been isolated that are equal to or exceed U.S. commercial hybrids in yield. In addition to this amount of fixable vigor, great heterosis exists in selected crosses. Great variation also exists in all the components that go together to make up nutritional quality. Percent protein varies from 6 to over 20 percent with most of the relatively economical lines falling in the 8 to 15 percent range. The variations in essential amino acids as percent of protein and certain ratios as well as oil were: lysine, <1% - 3.8%; threonine, 2.5% - 5.3%; tryptophane, <1% - 4.5%; methionine + cystine, 98% - 4.62% isoleucine, 3.76% - 5.51%; isoleucine/leucine ratio, .272% - .380% (highest best); and oil, 1.2% - 6%. Tannin variation is at least 0.2 to 2.0% (Chang and Fuller, 1964). At Purdue the catechin equivalent variation using the vanillin-HCl method (Burns, 1963) was 0.4% - 13.7%. There was a bimodal distribution over widely variable selected lines and commercial hybrids. Mean *in vitro* digestibility ranged from 38 - 93% and was closely correlated (r = +.95) with catechin equivalents. Weight gains by weanling rats on selected sorghum lines with mineral and vitamin supplementation, showed a range from losses of 3.28 gm to gains of 16.8 gm in two week periods. (See table 5). These weight gains were related to levels of crude protein, limiting amino acids and *in vitro* dry matter disappearance rates. Great variability in the collection exists in grain size with a range of .5 g/100 seeds to over 5.5 g/100 seeds. There is also much difference in seed color, panicle size, opening and exertion, height, lodging resistance, leaf number, angle and size and all other observable phenotypic characteristics. The superior types for chemical composition and digestibility occur in almost all of the races or phenotypes which are in turn from many sources of origin. This broad array of variability in types associated with improvable yield and nutritional value is important in order to satisfy the taste and acceptability preferences of humans for food and for feeding uses for various classes of livestock. In most sorghum improvement projects in the world there is a need for a wider selection for both yield and nutritional quality from the germplasm available in the world collection. The available collection items can greatly supplement the relatively narrow base in present commercial production or in local production which is available for food, feed and processing. This wide diversity of type, selected from the collection, is not only important for yield and nutritional quality potential, but it represents diversity of both type and cytoplasm that are important for resistance to diseases and insects presently know or that may occur in the future.

Various combinations exist of protein level, certain amino acid levels and their ratios, starch amount and availability and total digestibility as influenced by polyphenolic compounds (including "tannin") and vitreousness or hardiness, which can be recombined for total nutritional improvement.

The AID-sponsored project at Purdue is in the process of cataloging the varieties that exist in the collection and is making available seed and information to interested investigators around the world. The information on selected lines that is presently being cataloged includes origin, yield potential, protein content, amino acid content, certain phenotypic characteristics, oil content, location performance and feeding performance values or indicators. Improved yield and nutritional quality factors have been discovered to exist in all types and races of sorghum. Present investigations includ trials to identify lines and hybrids that have yield and nutritional stability across various environmental and management conditions. Therefore, breeders with particular objectives of taste preferences, seed type, local resistances, color, panicle type, height and canopy will have the opportunity to incorporate these new materials into their sets of objectives from the most adapted of several sources.

B. Composition Including Protein, Limiting Amino Acids and Oil

Protein content apart from yield means relatively little. Very high protein contents may be obtained when yields are low and vice versa with the same lines or hybrids, therefore, both need to be determined as soon as possible.

Crude protein is similar for mature and immature grain, but less energy is available in immature grain (Deyoe, et al., 1970). Higher lysine, aspartic acid and glicine amount are found in immature grain, but lower amounts of glutanic acid, protein and leucine are found. This indicates further the misleading characteristic of crude protein alone in sorghum nutrition and stresses the importance of considering grain yield, protein (available protein per unit area), amino acid balance, and availability of starch and digestibility in a total ration or menu for a favorable response.

The protein amount is also affected by sampling procedures which take into account significant plant variations border effects, including heights and maturities, foreign materials, seed density, variations within panicle, soil fertility level, and other management practices. In replicated experiments for protein analysis, coefficients of variation of 4% - 10% can be obtained where adequate sampling procedures are used. An adequate sample should include portions of ten or more different representative panicles of open pollinated seed from each bordered plot. Investigations to date show individual plant composition data to be inadequate in measuring F_2 plants as reported by Collins (1969). He described the lack of validity of a single plant sample to represent a line since he found significant differences among single plant samples within a pure line. Procedures to date have been to measure the average progeny of such plants rather than the individual plants themselves. For maximum precision of genotype comparisons all samples must be made from the same location and in a given year. The compositions are usually significantly different from location to location and year to year as shown by present AID Purdue work.(Table 1). The genotypic differences are of sufficient magnitude, however, to allow selection for superior performance under these conditions.

Variability of seed size (2.63 - 4.02 g/100 seeds), percent oil

(3.07 - 5.28%), percent embryo (10.5 - 13.9%) and the variability in percent protein and percent lysine of protein in the whole seed, embryo and embryo free portion of the seed have been investigated by Rodriguez (1969). The data presented in table 2 illustrates the variability he found in percent protein and percent lysine of protein in the whole seed as compared to embryo and non-embryo seed portions. Unpublished work done as a followup and as a part of the AID-Purdue Sorghum Project showed ranges of 9.67 to 14.24% protein in the whole seed, 15.60 - 21.58% protein in the embryo, 8.42 - 14.07% protein in the non-embryo seed protein, 5.42 - 11.54% embryo of the whole seed, 2.20 - 5.22% oil of the whole seed with the weight of 100 seeds varying from 1.5056 - 3.3632 grams per 100 seeds. The correlations from this work and presented in table 3 show the potential for improving protein content by altering embryo size and oil content. An even wider range of seed size has been recently observed (0.5 gm to 5.5 gm/100 seeds) at Purdue University.

C. Digestibility and Feeding Values

Sorghum has a much greater range of digestibility values than the other major cereal grains of rice, wheat and maize. Wide variations in amounts of lysine and sulfur bearing amino acids (methionine and cystine) were reported (Nawar, et al., 1970). They showed that lysine was the first limiting amino acid followed by the S-amino acids and threonine for weanling rats. Supplements of these amino acids or dried skim milk gave improved growth and nitrogen deposition with 3 of the 17 samples studied, but not all responded favorably to amino acid supplementation. It is also reported that lysine, vitamin and mineral supplements gave about the same rat growth response as casein added to the grain sorghum (Howe, 1970), however, in this study lysine supplement alone gave no response, but Ca alone did give a significant response in rat growth rates.

When the protein was extracted from selected grain sorghum and opaque 2 corn (Skoch, et al.,1970), the corn yielded twice the extractable protein as the grain sorghum. The glutelin fraction contained the major soluable protein of both. McGinty (1969) found that the pericarp of varieties that digested poorly, when separated and added to sorghum grain that normally digested well, would depress their digestion. This result could be induced by tannic acid and lessened by polyethylene glycolin in an <u>in vitro</u> dry matter digestion (IVDMD) system (Tilley, et al., 1963). This indicates further the necessity of considering factors influencing utilization in addition to those affecting yield, protein and amino acid composition.

Preliminary work at Purdue on percent distribution of the protein fractions in sorghum is shown in table 4 . Two pairs of sorghum lines were contrasting significantly in IVDMD levels and in rat growth. Significant shifts in four of the five fractions studied occur between lines with high and low IVDMD. The fraction of whole kernel and endosperm react differently but the differences between high and low IVDMD lines still existed

A wide range in dry matter digested (17 - 71%) was found by the nylon bag technique (Anthony and Haveland, 1971) when ground grain samples of approximately 1,000 lines from the collection were tested. In his work a bird resistant check averaged 41%.

Light trashy grain depresses nutritive value more than light immature grain (Hinders, 1971). Mitjavila, (1970) was able to depress significantly the absorption of glucose and methionine in the small intestine of a mouse from 6 to 10% with 1 mg/1 of gallotannic acid; but the uptake of butyric acid was not depressed until the concentration of gallotannic acid exceeded 10 mg/1. Conner, et al., (1969) illustrated with growing chickens a reduction in growth rate as the tannin content of the grain was increased which could partially be alleviated by supplementation with large amounts of methionine and chloine, but feed intake was depressed and the tannin showed a toxic effect.

Peterson (1969) reported a ration of 49.32% sorghum, 0.68% technical tannin with 50% basal diet affected feed consumption, rate of gain, chemical composition and edible quality of chicken meat produced on the diet. This difference was not attributed to a difference in metabolizable energy and protein intake. The availability of the amino acid did not appear to be related to seed coat or to tannin content as several sorghums with low protein quality were also low in tannin (Stephenson, et 1971). The influence of tannin and related substances in the sorghum grain remains an area of additional nutritional research and breeding control. He stated that the first limiting amino acid for poultry was not lysine but methionine and some sorghums offer relatively high methionine quantities. The amino acid content is very variable and high levels are judged to be possible through plant breeding.

Most of these investigations to date have been made on a relatively narrow germplasm base. There is available now much new relatively high yielding germplasm which varies greatly in composition and which will allow selection of variety improvement in protein amount and amino acid composition as well as in types with adequate digestibility, palatability or acceptability and having the necessary resistances. Such research points to the practicality of the potential development of a more balanced nutritional sorghum. The data in table 5 which show the results of recent rat feeding trials at Purdue with sorghum lines varying significantly in rate of *in vitro* dry matter disappearance (IVDMD) and protein percent, lysine, threonine and methionine.

The weight gains at the end of two weeks relates very closely with those at the end of four weeks. The two week weight gain therefore is now considered to be sufficient to indicate the wide difference in nutritional value of various sorghum lines for rat growth. Consumption does increase with the rate of IVDMD but not in a straight line relationship. Correlation coefficients for these factors are shown in table 6. Significant negative correlations exist between protein and lysine and lysine with IVDMD, but positive relatively strong correlations of the same magnitude are seen between protein and IVDMD and protein and weight gain. Also IVDMD with weight gain is in the same good relationship with weight gains. The correlation of 4 = +.98 for weight gain at two weeks and 4 weeks and similar values for other trials have been the basis for going to two week rat feeding trials. Methionine is significantly and positively correlated with percent protein, IVDMD, weight gain, protein x lysine, feed consumption and protein x IVDMD.

The presence or absence of the brown testa observed in the mature caryopsis is controlled by two dominant gene pairs (Stephens, 1946). Observations to date at Purdue indicates that the presence of the brown testa is associated with low IVDMD and high polyphenol ("tannin") content.

D. Inheritance of Factors Affecting Nutrional Value

Fourteen diverse inbreds selected from good yield combiners in the world collection of sorghum grown at Purdue University were crossed onto four male sterile lines (Abifarin, 1969) and significant differences were found among hybrids for maturity, leaf numbers, height, flag leaf area, panicle exertion, panicle length, threshing percent, grain weight per panicle, 100 seed weight, protein percent, lysine as percent of protein, grain yield, protein yield, and lysine yield.

Grain yields among the 56 hybrids ranged from 5,854 to 17,288 kg/ha while the parents ranged from 4,001 to 10,363 kg/ha. The ranges for percentage protein was from 9.1 to 14.1% for hybrids and 9.9 to 15.7% for their parents. Values for lysine were 1.69 to 2.27% for hybrids and 1.60 to 2.19% for their parents. Phenotypic and genotypic correlation coefficients for yields vs. protein were -.483 and -.483 while corresponding values for yield vs. lysine were .258 and .337. Combining abilities for all characters were much higher for general combining ability (GCA) than for specific combining ability and G.C.A. was highly significant for all characters among males. Narrow sense heritability values were 99% for height, 77% grain yield, 85% percent protein and 62% lysine.

The relative importance of certain phenotypic characters with respect to grain yield and quality, the intercharacter correlations, combining ability and heterosis were studied (Bantayehu, 1971) in both parental and F_1 generations of 24 phenotypically diverse sorghum lines selected as diverse types from the world collection. Twenty-one characters were measured and there were highly significant genotypic differences obtained in both generations for all characters indicating that progress on each could be expected from a breeding program. General combining ability was predominant to specific combining ability for almost all of the characters studied. Some higher yielding inbred lines produced inferior hybrids and a few poorer performing inbreds resulted in superior hybrids for yield and protein amount and quality. The necessity of direct testing of inbreds for their ability to produce good hybrids was stressed.

Grain yields for hybrids ranged from 4,282 to 8,639 kg/ha while the range for their parents was 4,418 to 7,536 kg/ha. The range for protein percent was from 7.75 to 12.60% for hybrids and 10.30 to 14.85% for their parents. Lysine ranged from 1.61 - 2.67% for the hybrids and 1.54 to 2.55% for their parents. Heterosis over the better parent ranged from -36.10 to 29.04% for grain yield. The heterosis range for percent protein was -31.34 to 15.20%, while the lysine range was -16.28 to 30.88%. Certain genotypic combinations were found to exhibit positive heterosis for both grain yield and percent protein simultaneously in spite of the low but significantly negative correlation between the two.

The morphological characters studied included leaf number, flag leaf length, width, and area, length, width and area of third leaf from the top, plant height, stem diameter, head exertion, panicle length, tillering, lodging, number of heads per plot, and threshing percentage. These factors were not good indicators of yield, percent protein, percent lysine and oil. To date it appears that direct selection for yield and quality may prove to be more effective than the use of these traits as indirect selection indices in the world collection and many other diverse breeding sources (Bantayehu, 1971).

Working with 65 sorghum genotypes Collins (1969) found significant correlations of grain yield with percent protein at r = -.195** and percent protein with percent lysine r + -.304**, but at a much lower level than many people had previously hypothesized. In an incomplete diallel (Collins, 1969) with 12 restorer lines crossed to four male sterile testers there were significant differences among restorer lines in general combining ability for yield, protein, and lysine. The variation due to specific combining ability was not significant for any of these characters. In a nine parent diallel (Collins, 1969) it was shown that both general and specific combining ability were important for all three characters with general combining ability being far more important for percentage protein and less important for yield and percentage lysine. Several hybrids, with parents appearing diverse in type, had considerable heterosis for yield, but only a few hybrids showed heterosis for percentage protein while no heterosis was observed for percentage lysine. In this study grain yield and percent protein had a negative correlation of $r = -.57$ and percent protein with percent lysine had $r = -.51$.

Collins (1969) described the genotype x location interaction on 11 genotypes for two years at three locations. The first order interactions were not significant for any character studied but the genotype x location x year interaction was highly significant for grain yield, percent protein and protein yield.

IV. PROCESSING AND UTILIZATION

A. Feed Processes

Albin, (1971) Hart, et al., 1970) and Blessin (1971) and others have reported various methods of processing that improve the nutritional quality of sorghum flour and processed grain. Method (Albin, 1971) of processing whole grain include its being ground, dry rolled, soaked, pelleted, steam-rolled, steam process flaked, pressure cooked flaked, high moisture storage, popping, steam pressure popped, dry heat processing, micronizing, exploded, extruded and infused with amino acids (Blessin, 1971). In most cases these processes add considerable to the cost and are difficult to adapt to small feeding operations, but have improved the feed lot performance of sorghum grain.

B. Food Uses

Blessin (1971) was able to remove the pericarp leaving the endosperm, the aleurone layer and germ essentially intact. Essential amino acid balance can be altered significantly by infusion but no feeding values were reported. One of the potential uses in many developing countries is the use of sorghum in a blend to extend wheat supply for bread making. Research by Hart, et al., (1970) reported that the quality of sorghum flour can be improved for such purposes. The addition of methylcellose increases gas retention and improves texture. Glyceryl monostearate as an additive improves the softness of the bread. The processing of grain for human food will no doubt increase for urban populations and such processes should be much more important in developing countries than at present. Also as more wheat and rice become available these preferred cereals will be used more for human food and improved nutritional sorghum types will be more important for feed grain for livestock. The adaptation of sorghum as a crop to follow rice makes it important to investigate new uses of sorghum for rice consumers in addition to providing some meat to go with the rice. As other grains take over primary areas of grain production, sorghum and millets will undoubtedly become more critical in marginal areas for direct use as human food and feed grain.

V. FUTURE PROSPECTS

The potential for the continued improvement of grain sorghum yield, quantity and quality of protein, utilization, and digestibility is promising. The identification of collected materials now having useful individual and multiple characteristics is well advanced. This is enabling the establishment of diverse populations for selections of recombinations from which lines and hybrids with increased yield and improved nutritional values will result. The continued maintenance of diverse materials in a collection will allow for additional selection for an establishment of populations and selected crosses to overcome nutritional deficiencies, disease, insect and pest resistances, climatic adversities, and individualized acceptance standards. The ultimate increase in tropical use of sorghum as a feed crop will stimulate further the demand for yield potential, quality improvement and environmental adaptations. The current cataloging of sources, yield performances, nutritional values, phenotypic characteristics and environmental interactions of the diverse sorghum collection will continue to stimulate selection for and development of improved quality varieties with specific and widely adapted performance standards. As the pressure for increased food and feed continues the importance and utilization of quality sorghum grain will be met with increasing numbers of lines and hybrids having tested and improved yield performances and nutritional qualities.

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Table 1. Genotype by Environment Interactions at Six Locations with Twelve Lines and Twenty-Three Hybrids in 1970.

	Analysis of Variance+					
	% P	% L	P•L	Yield	Y•P	Y•P•L
Locations	**	**	**	**	**	**
Varieties	**	**	**	**	**	**
L x V	*	NS	**	**	**	**

* - significant at 0.05
** - significant at 0.01
NS - not significant

\+ - yield data not available for Nebraska location.

Table 2. 1970 Studies on Embryo-Endosperm Proportions and Compositions for Twenty-Five Sorghum Lines with Oil Content Ranging from 1.92 - 5.22% With a Mean of 3.88%.

Correlations:	% P of Whole Seed	% P of Embryo Seed Half	% P of Non-Embryo Seed Half	% Oil in Whole Seed	% Embyro of whole Seed	L as % of P of Whole Seed	% Meth. of P in Whole Seed
% P of Whole Seed		0.954	0.164	0.667	0.255	0.075	0.297
% P of Embryo Seed Half			0.247	0.561	0.126	0.062	0.258
% P of Non-Embryo Seed Half				-0.042	-0.306	0.035	0.243
% Oil in Whole Seed					0.710	0.318	0.393
% Embryo of Whole Seed						0.377	-0.058
L as % of P of Whole Seed							0.024
% Meth. of P in Whole Seed							

Table 3. Sorghum Composition of Whole Seed Compared to Embryo and Embryo-Free Seed Section.

Seed Section:	WHOLE SEED		EMBRYO		EMBRYO-FREE	
	% Prot.	% Lys.	% Prot.	% Lys.	% Prot.	% Lys.
Variety:						
MX0793	12.1	1.9	21.3	5.7	10.8	1.1
0819	13.4	2.1	24.7	6.2	11.7	1.3
RS610	11.0	2.0	22.8	5.9	9.6	1.1
MX1884	10.6	2.0	22.9	5.5	9.4	1.2
0793	13.5	1.6	18.1	5.8	12.4	1.1
Mart.B	13.2	1.8	22.5	6.5	11.6	1.0

Table 4. Percent Distribution of Proteins in Sorghum Grain Fractions (Landry & Moureaux Method).

Sample Number Grain Section	025-042-1 Kernel	025-154 Kernel	925-006 Kernel	925-074 Kernel	025-042-1 Endosperm	025-154 Endosperm	925-006 Endosperm	925-074 Endosperm	Protein fractions obtained in corn
Solvents %									
Sodium chloride	19.2	4.6	19.2	4.3	7.9	2.7	8.5	3.1	Albumins Globulins
Isopropanol	18.1	10.3	21	2.1	16.4	16.2	21.0	14.6	Zein
Isopropanol + 2 Mercaptoethanol	21.2	16.0	24.7	24.1	35.7	26.1	35.8	30.9	+G_1
Borate buffer, pH 10 + Mercapto-ethanol	8.6	13.4	5.6	15.6	11.1	11.4	6.8	12.2	‡G_2
Borate buffer, pH 10 + 2 Mercaptoethanol + Sodium dodecyl sulfate	32.9	55.7	29.5	53.9	28.9	43.6	28.0	39.21	‡G_3
Protein %	9.4	10.1	11.2	7.7	8.63	9.52	9.95	7.21	
Lysine %	2.7	2.65	2.70	2.79	1.87	2.13	1.66	2.00	
I.V.D.M.D.1/	91	48	94	66	91	49	94	66	
Average weight gain per week in rat feeding experiments	6 2/	-9 2/	8.7 3/	-0.2 3/					

1/ *In vitro* dry matter disappearance.

2/ 1 week duration.

3/ 4 weeks duration.

+G_1: Alcohol soluble glutelin. Composition is closely related to that of zein.

‡G_2: Saline soluble glutelin. Composition is intermediate between those of zein and saline soluble proteins.

‡G_3: 'Zeanines'. Composition is closely related to that of saline soluble proteins.

le 5. Sorghum Project Rat Feeding Studies - Purdue University - May 1971.

Sorghum Lines	Feed (1) Consumed (g)	Total wt.gain 2 weeks (g)	Total wt. gain 4 weeks (g)	*in vitro* DMD (2) (%)	Protein (%)	Lysine of Protein (%)	P × L	Threonine of Protein (%)	Methionine of Protein (%)	Protein × *in vitro* DMD
925006	226	11.81(3)	34.81	93.6	12.3	2.70	.332	3.24	1.50	1273
925018	175	07.63	20.27	91.5	14.3	1.98	.283	3.47	1.29	1199
IS2319	191	05.73	15.47	87.4	11.8	2.53	.298	3.11	0.69	0970
954116	182	04.45	16.93	89.7	11.9	2.34	.279	3.12	0.89	1067
954054	170	03.90	15.23	83.5	10.4	2.46	.256	3.10	0.89	0818
925060	174	03.70	11.80	68.2	12.4	2.65	.329	3.27	1.22	0791
954131-2	156	02.90	12.51	90.3	11.8	2.22	.263	3.05	1.00	0975
925074	156	-03.28	-00.58	66.4	09.0	2.68	.242	3.58	0.25	0671

(1) 95% grain sorghum, 5% vitamin and mineral supplement.
(2) DMD = Dry Matter Disappearance.
(3) Weigh gains connected by a line are not significantly different (.05 level).

Table 6. Sorghum Project Rat Feeding Suty Correlation - Purdue University, May 1971.

	% Protein	% Lysine of Protein	% *In vitro* DMD	Total g gain 2 wk.	Total g gain 4 wk.	P × L	g Feed Consumed	P × *in vitro*	% Threonine	% Methionine
% Protein	1.000	-.587**	.562**	.646**	.613**	.581**	.361*	.753**	-.084	.795**
% Lysine		1.000	-.539**	-.040	-.081	.312*	.331*	-.410**	.063	-.225
% *In vitro* DMD			1.000	.707**	.760**	.157	.491**	.871**	-.490**	.520**
g Total Wt. gain 2 wk.				1.000	.986**	.727**	893**	.872**	-.254	.837**
g Total Wt. gain 4 wk.					1.000	.656**	.873**	.889**	.316*	327**
P × L						1.000	.754**	.474**	-.148	.726**
g Feed consumed							1.000	.697**	-.172	.578**
P × *In vitro*								1.000	-.165	.729**
% Threonine									1.000	-.216
% Methionine										1.000

* Significant at .05 level
** Significant at .01 level